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Testing of Boost Rectification of Back-to-Back Converter for Doubly Fed Induction Generator

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***Abstract*— This paper describes the testing of boost rectification required in the back-to-back converter used in doubly fed induction generator (DFIG) based wind energy conversion systems (WECS). In this work testing is carried out on the single phase rectifier section of back-to-back converter. Detail design of components of back to back converter is explained. The hardware module of this back-to-back converter is fabricated in the departmental laboratory. dSPACE and Microcontroller 8051 is used for implementing the control. Results show that required boosting is satisfactorily obtained.**

***Index Terms*— Boost rectifier, DFIG, RSC, GSC, PWM, IGBT, WECS**

I. INTRODUCTION

The worldwide concern about environmental pollution and a possible energy shortage has led to increasing interest in technologies for the generation of renewable electrical energy. Among various renewable energy sources, wind power is the most rapidly growing one in the world.[1] With the recent progress in power electronics, the concept of a variable-speed wind turbines equipped with a DFIG is receiving increasing attention because of its advantages over other wind turbine generator concepts. In the DFIG concept, the induction generator is grid connected at the stator terminals; the rotor is connected to the utility grid via a partially rated back-to-back converter, which only needs to handle a fraction (25 to 30%) of the total DFIG power to achieve full control of the generator. A block diagram of such a system is as shown in Figure 1.

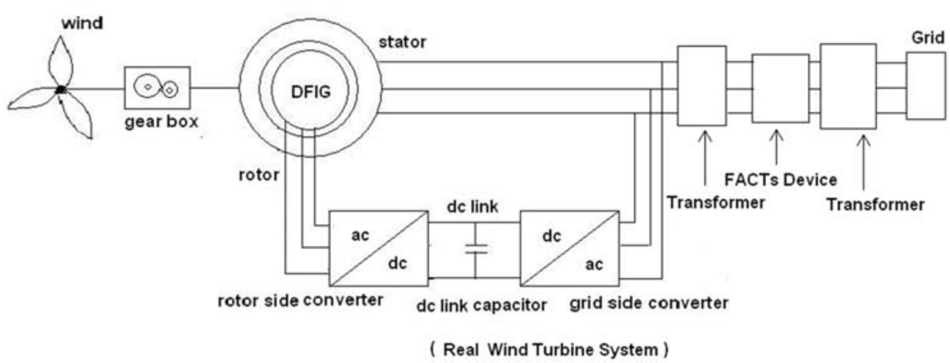

Figure 1. Block diagram of WECS

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The back-to-back converter consists of a rotor side converter (RSC) and a grid side converter (GSC) connected back to back by a DC link capacitor. In this paper the detail design of RSC and GSC is given for a laboratory model. Design of capacitor is also carried out and finally all component values are investigated [2]. A prototype model of rating 1 kW is fabricated in the laboratory and then various tests are taken on this model for its successful operation. For bidirectional power flow it is essential to boost the rectifier voltage at the required level .Microcontroller 8051 is used as a tool for boosting this voltage.

II. Design Of Back-To-Back Converter

A. Back-to-Back Converter Modelling

Mathematical modelling [3-5] of converter system is realized by using various types of models, which can be broadly divided into two groups: mathematical functional models and Mathematical physical models (either equation-oriented or graphic oriented, where graphic-oriented approach is actually based on the same differential equations).

This paper proposes a graphic-oriented switch-by-switch representation of the back-to-back PWM converters with their modulators for both rotor- and stator-side converters Figure 2, where both IGBT and reverse diode devices are represented as a two-state resistive switch .The two-state switch can take on two values, R_{ON} (close to zero) and R_{OFF} (very high).

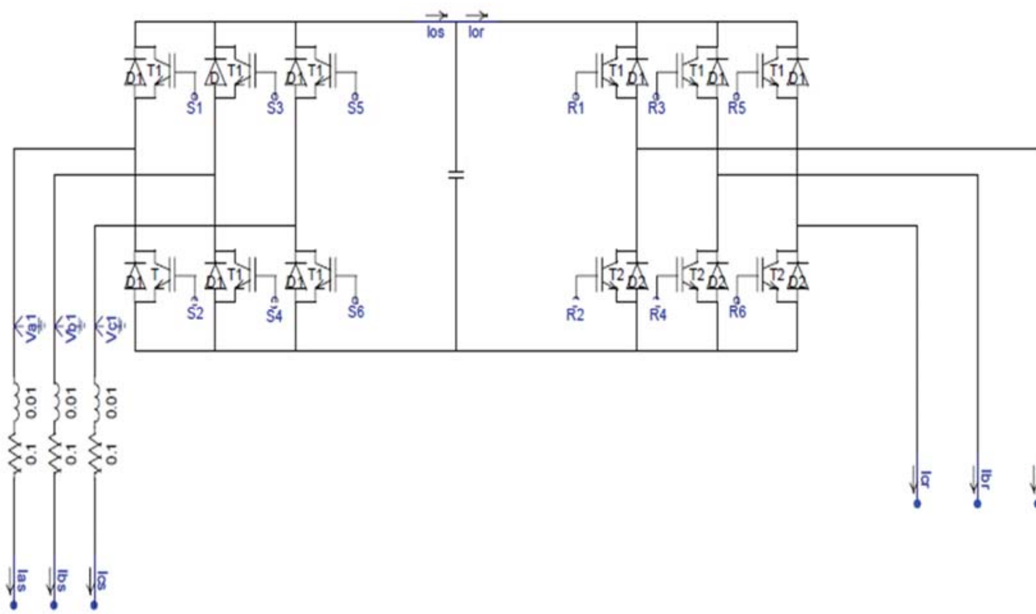

Figure 2. Back-to-back PWM converter structure

B Selection of Components [6, 7]

1. Switches

To implement a Back-to-Back Converter, IGBT is used as a switch because of its high current carrying capacity, high switching frequency and other advantages as compared to MOSFETS. As per the requirement, the IGBT chosen was of 1200V, 30A. for GSC and 600 V, 70 A for RSC.

2.DC link capacitor

The value of the capacitor can be determined as:

$$c \geq \frac{T_{sw} P_{load}}{\Delta U_{dc} U_{dc}} \left[1 - \frac{e_{dc}}{U_{dc}} \right] \qquad (1)$$

Here,

$\boldsymbol{T_{sw}}$ = Switching frequency, Hz

$\mathbf{P_{load}}$= Load power, kW

$\mathbf{u_{dc}}$= DC link voltage, V
$\mathbf{\Delta u_{dc}}$= change in DC link voltage, V
e_{dc}= supply voltage to the grid side converter, V
Using above equation value of capacitor is calculated and it is 100µF. Two commercially available capacitors of 470µF, 600V were chosen and connected in series so that their effective value is 235µF and the voltage rating is 1200V.

3. Driver Circuitry for IGBTs
Each IGBT needs a driver circuit for its operation. Figure 3 shows the complete driver circuit used for a single IGBT. Same circuit is used for all IGBTs.

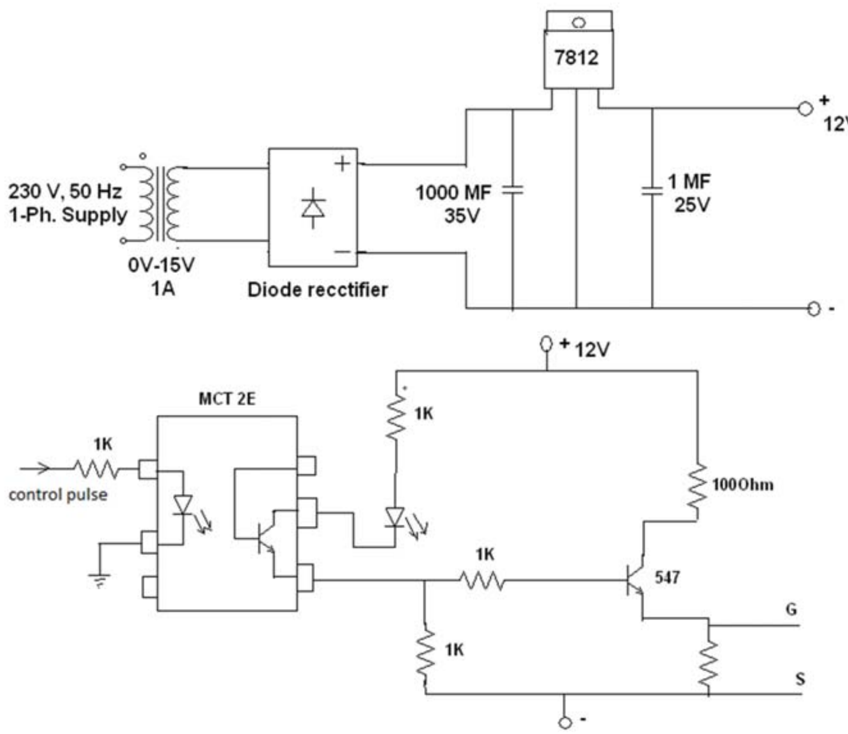

Figure 3. Driver Circuit

III. HARDWARE OF BACK-TO-BACK CONVERTER

Using the selected components as discussed in section II, a hard ware of back-to-back converter is fabricated in the laboratory. Block diagram of the same is shown in Figure 4.

IV. DSPACE

A. Introduction to dSPACE

dSPACE stands for Digital Signal Processor for Applied and Control Engineering. The dSPACE has become popular in industry in the implementation of automation and complex control. The Research and development work is carried out with the help of dSPACE.

B. Compatibility with dSPACE

1. Sensors
The sensors are required to interface the Back-to-Back Converter with dSPACE.

a. Voltage Sensors
The voltage sensors are required for two purposes i.e. to sense the AC mains voltage and DC link voltage across the capacitor. The way utilized is generally followed in digital multimeters (DMM). In this case, the

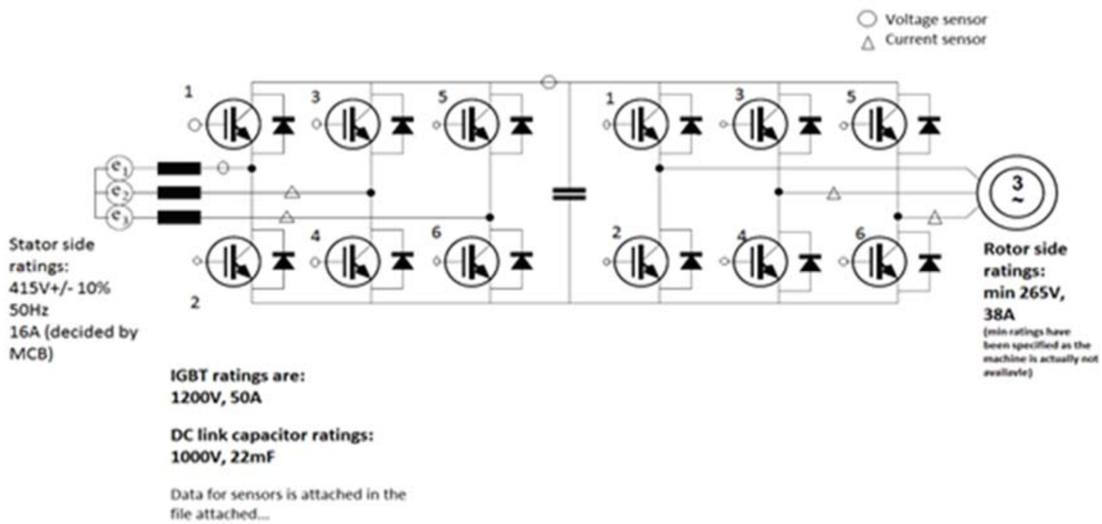

Figure 4. Block Diagram

voltage to be measured is applied across a potential divider arrangement. The voltage is thus divided in two parts. The voltage across lower resistance is taken to a Unity Gain Amplifier which is implemented using Operational Amplifier. The values of resistances in the voltage divider circuit are calculated depending on the voltage to be measured and the voltage that can be interfaced with the Operational Amplifier.

b. Current Sensors

It is proposed to use Hall Effect sensors for current sensing.

2. placing of sensors

In order to make judicious use of the ADCs available with the given dSPACE module, in spite of sensing voltages and current from all the three phases; a different strategy has been adopted. For the present strategy, the assumption made was that the three phase voltage and current are balanced. For voltage, strategy adapted is shown below in Figure 5. In this scheme, the voltage from one phase has been sensed and given to dSPACE. The signal is then multiplied with the sensor gain. The sensor gain can be calculated from the multiplying factor which can be estimated by taking the ratio of the output of sensor when input is maximum. The sensor gain is 10 times this multiplying factor as the dSPACE scales down the voltage at ADC from 0 to 10 to 0 to 1. The input is then divided by sin (ωt) to extract the amplitude of the signal. This amplitude is used to calculate the other two phase voltages by shifting the sin (ωt) by 120˚. Multiplexing these three signals, stator voltages of DFIG are obtained.

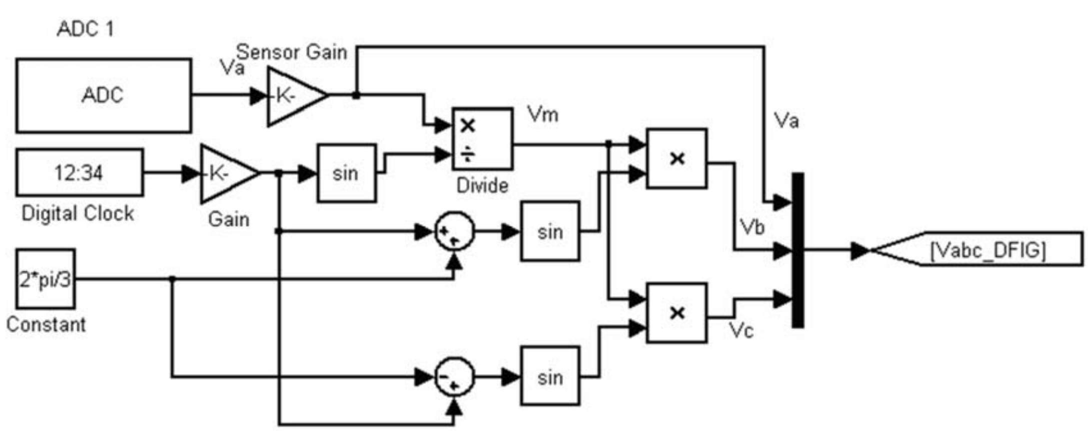

Figure 5.Voltage Sensing Scheme

The scheme for current is depicted in Figure 6 shown below. Similar to the assumption made in case of the voltage sensing, the voltage and current are considered to form a balanced three phase network. In this case, the three phase currents can be related as

$$I_a+I_b+I_c = 0 \qquad (2)$$

Thus it can be concluded that,

$$-1*(I_a+I_b)= I_c \qquad (3)$$

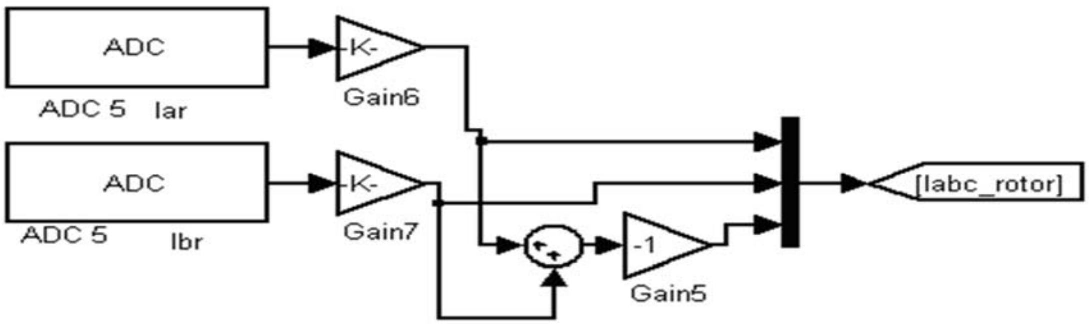

Figure 6.Current Sensing Scheme

For the DC voltage signal interfacing, one has to multiply the signal by sensor gain which can be calculated in the same way as for the stator voltage. In present text, pulses are required to drive two converters. Hence, for Grid-Side Converter, the PWM block in dSPACE has been attached whose pulses are taken from the PWM port. For the rotor side converter, the MATLAB PWM block has been used whose output has been taken from the DACs. In this way, all the twelve pulses required have been catered. Pulses obtained from dSPACE are shown in Figure 7 and Figure 8.

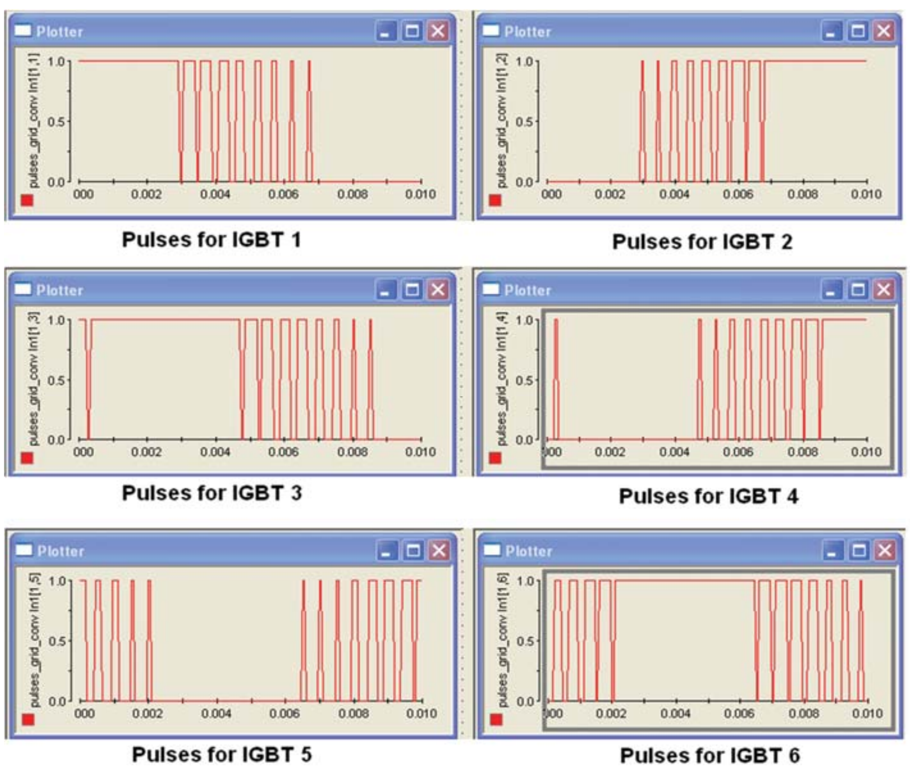

Figure 7.PWM Pulses for Grid Side Converter

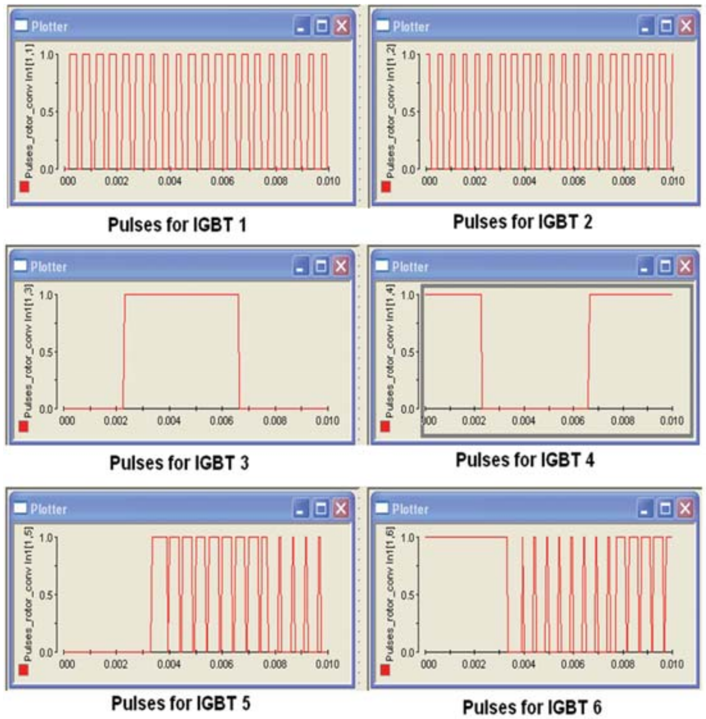

Figure 8.PWM Pulses for Rotor Side Converter

V. MICROCONTROLLER 8051

Using dSPACE the firing pulses are obtained successfully. But due to limitations of dSPACE it was difficult to use it for three phase circuit when the three phase voltages are unbalanced. Though presently only single phase circuit is tested but considering the future work it is decided to use Microcontroller 8051 for obtaining the pulses to fire IGBTs. Pulses obtained from analog circuit are given to two interrupt pins of 8051 and output pulses from 8051 are given to driver circuit and IGBTs as shown in Figure 9 [8, 9]. Some important features of 8051 are:8 bit ALU., 16 bit PC and DPTR., 8 bit stack pointer and 8 bit PSW., 4K internal ROM, 128 bytes of Internal RAM., 32 bits arranged as four,8 bit ports P0-P3., Two 16 bit timer/counters, T0 & T1., Full duplex serial Port.

VI. TESTING OF BACK-TO-BACK CONVERTER

Primary tests are to be carried out for testing the back to back converter [10]. Following tests were carried out:

A. Checking of diode rectifier

Both GSC and RSC are fabricated using IGBTs. These IGBTs are having inbuilt diodes. Hence without firing the IGBTs, a simple test is carried out to test whether it works as diode rectifier or not. Both converters had given the satisfactory results. Sample voltages from 5V to 30V are given as input and output dc voltages recorded. Table I and Table II shows the results obtained. Expected dc voltages are obtained by using formula $V_{dc} = 3\sqrt{3}\, V_m/\pi$.

B. Testing of IGBTs using dSPACE pulses

dSPACE pulses as shown in Figure 7 and Figure 8 were applied to IGBTs of both RSC and GSC. All IGBTs using these pulses fired successfully.

C. Testing of boost rectifier operation

A simple analog circuit is built for boost rectifier operation. [11,12]. For this purpose a novel technique is used as shown in Figure 10 which collects zero crossing detector (ZCD) signals of the ac mains input and

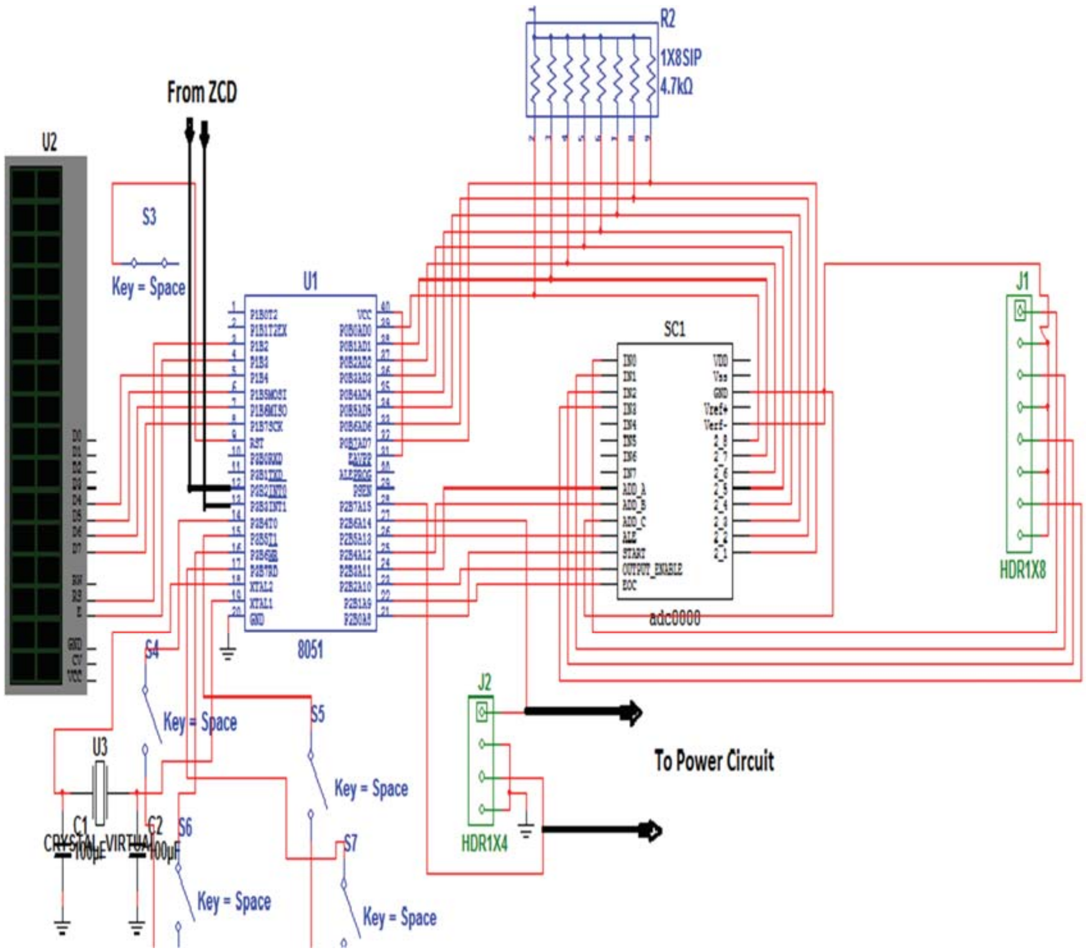

Figure 9.Microcontroller 8051 Circuit

provides them to the microcontroller interrupts which in turn generates the necessary gate control signals for IGBTs. Circuit is first built for single phase rectifier. Pulses obtained from this circuit were given as interrupts to microcontroller 8051. Output from microcontroller is then given to gates of each IGBT of single phase rectifier circuit of back to back converter. The same circuit is first simulated in MULTISIM. Circuit diagram of analog circuit as shown in Figure 10 and simulated results Figure 11 are as follows:

TABLE I. VOLTAGES FOR GSC

Vrms	Vdc(expected)	Vdc(actual)
5	11.69	12
10	23.40	24
15	35	36.7
20	46.7	48
25	58.47	60
30	70.17	72.3

TABLE II. VOLTAGES FOR RSC

Vrms	Vdc(expected)	Vdc(actual)
5	11.69	12.5
10	23.40	25
15	35	36
20	46.7	47.5
25	58.47	61
30	70.17	71

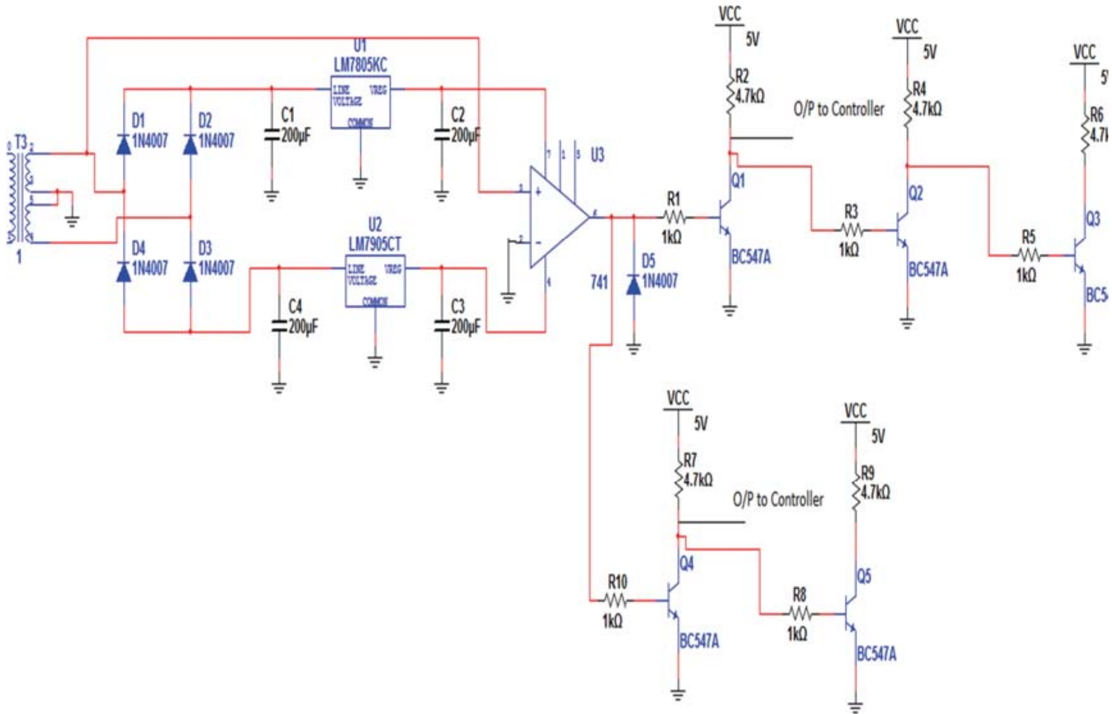

Figure 10. Analog circuit for boost rectifier operation

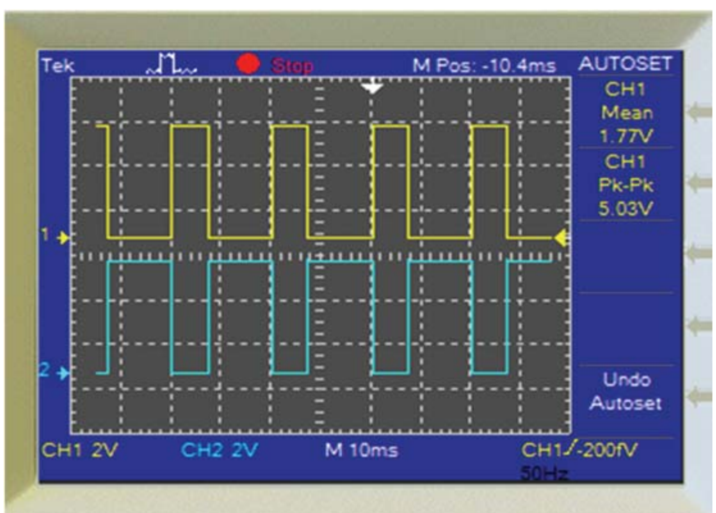

Figure 11.Simulation Result

The pulses obtained from analog circuit as shown in Figure 10 are utilised for controlling the diagonally opposite IGBT pairs of the single phase rectifier which works as a boost rectifier. The two distinct signals which are shown in Figure 11 by yellow and blue colours are used for activating the interrupt inputs of 8051. This further generates the gate control pulses for IGBTs with predetermined delay time which is controllable by programming the microcontroller.

Hardware circuit for the system is as shown in Figure 12. The output voltage of the boost rectifier for various pulse widths are shown in Table III.

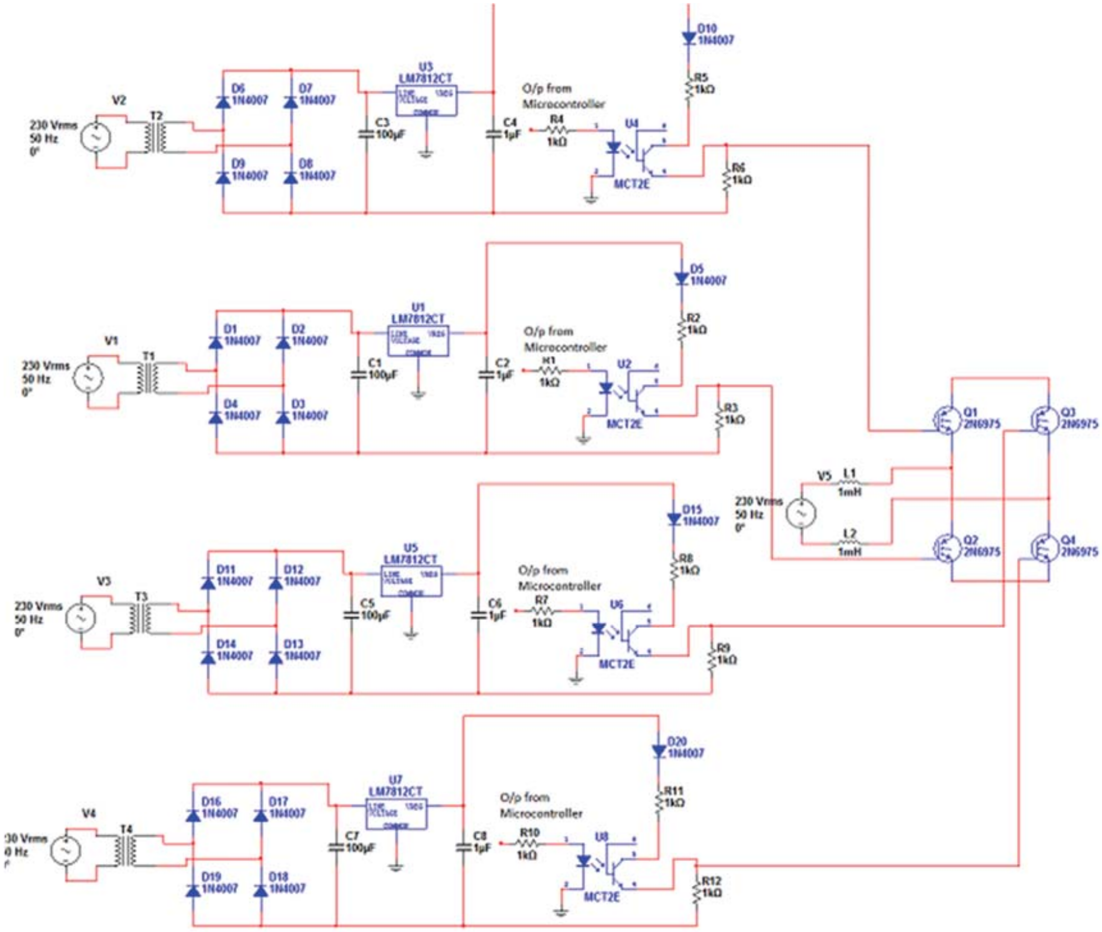

Figure 12.Hardware Circuit

TABLE III. HARDWARE RESULTS

Vrms	Minimum Pulse Width		Pulse width increased	
	Without Load	With Load	Without Load	With Load
10	51.5	15	55	16
20	67	28.5	72	31
30	78.4	43.4	88	44.5
40	90.3	58.5	98	61.5

The test is performed for input voltages between 10 to 40 volts ac rms, which are downscaled from their nominal values between 0 to 230 volts.

VII. CONCLUSION

In this paper a brief description of a wind energy conversion system was presented. Modelling of back to back converter, design of components and testing of back to back converter for boost rectification is then detailed. The entire tests carried out on Both GSC and RSC have given satisfactory results.

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